CHAPTER 7

FLOWCHART PREPARATION

Flowcharts are a useful tool when you want to evaluate the performance of an entire system, because they provide a means for organizing and presenting operating data. More specifically, flowcharts can be used for the following purposes:

- Evaluating process operating changes that are affecting control device performance
- Identifying instruments that are not working properly
- Identifying health and safety problems
- Communicating effectively

As discussed later, an expanded block diagram flowchart has been adopted. Major components are shown as simple blocks, rather than using complex sketches resembling the actual equipment. A set of conventional instrument symbols and major equipment symbols have also been adopted, primarily from conventional chemical engineering practice.

Flowchart Symbols

A complete flowchart consists of several symbols representing major and minor pieces of equipment and numerous material flow streams. It is important to be able to differentiate between the various types of material flow streams without sacrificing simplicity and clarity.

Major Components

Symbols for major components are shown in Figure 7-1. A square or rectangle is used to denote major equipment such as the air pollution control devices, tanks and vessels, or process equipment. Fans are denoted using a relatively large circle with a set of tangential lines to indicate the discharge point. A stack is shown as a slightly tapered rectangle. All of these symbols are shaded or filled with crosshatched diagonal lines so that it is easy to pick out the major equipment items from the gas handling ductwork and other streams leaving these units.

The items treated as major equipment depend on the overall complexity of the system being drawn and on individual preferences. These decisions are determined based primarily on the types of data and observations that are possible and the level of detail that is necessary to evaluate the performance of the overall system.

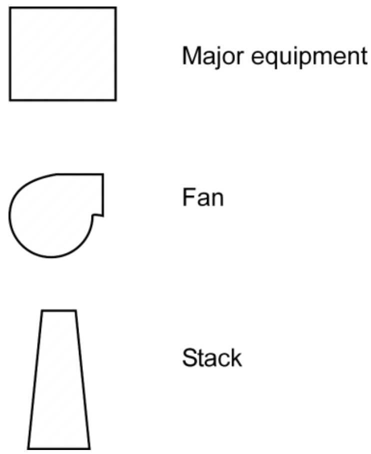

Figure 7-1. Major equipment symbols

Minor Components

A number of relatively small components in air pollution control systems should be shown on the block-diagram-type flowcharts in order to clarify how the system operates. A partial list of these minor equipment components is provided in Table 7-1.

Table 7-1. Minor Components

Fabric Filters	Wet Scrubbers
• Bypass dampers	• Pumps
• Relief dampers	• Nozzles
• Outlet dampers	• Manual valves
• Reverse air fans	• Automatic valves
Carbon Adsorbers and Oxidizers	
• Indirect heat exchangers	
• Fans	

Symbols for the minor components listed in Table 7-1 are shown in Figure 7-2. Note that all of these symbols are relatively simple and quick to draw.

Material Streams

The recommended symbols for the material streams are presented in Figure 7-3. Gas flow streams are shown as two parallel lines spaced slightly apart so that they are larger than other streams. This size difference is important, because it allows the inspector to quickly scan the flowchart and differentiate between gas and liquid material flow streams. Segments of ductwork connecting one major piece of equipment to another are labeled with an alphabetic character. Important liquid and solid material flow streams are shown as solid, single lines. Diamonds with enclosed numbers are used to identify each of these streams.

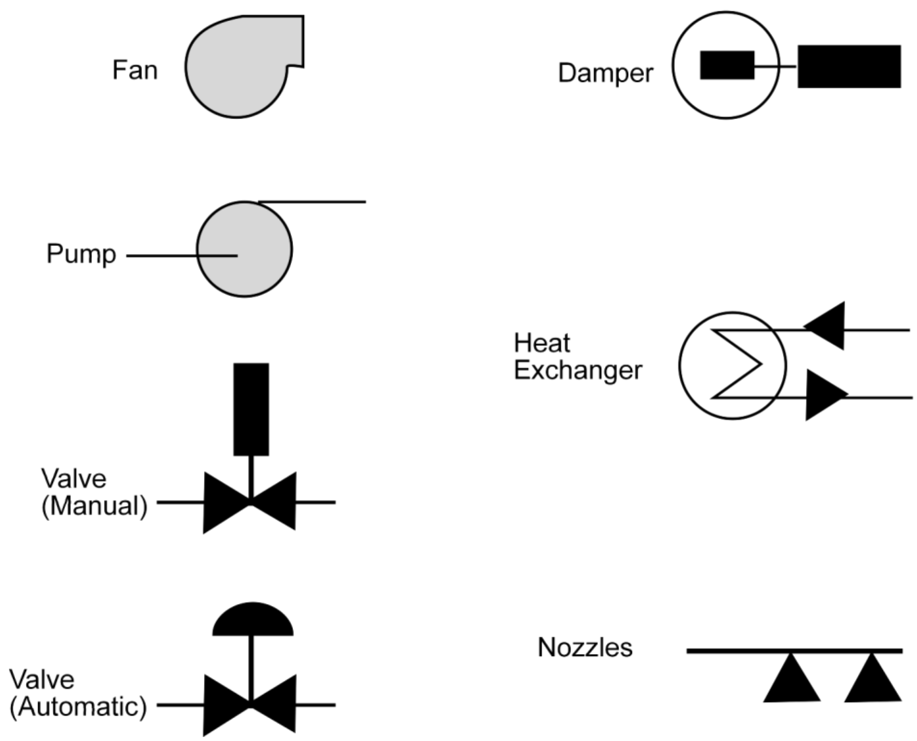

Figure 7-2. Minor component symbols

To avoid cluttering the drawing, some of the liquid and solid material streams for which operating data will not be necessary are unnumbered. These types of streams are often called *utility streams*. They provide necessary materials to the system being shown, and the characteristics of these streams are relatively constant. Typical utility streams for air pollution control equipment systems include make-up water, cooling water, and low-pressure steam. Natural gas, oil, and other fossil fuels can also be treated as utility streams to simplify the drawings. Instead of the numbered diamonds, these utility streams are identified either by using one of the codes listed in Table 7-2 or by a one- or two-word title. The codes or work titles are placed next to a "stretched-S" symbol, which is used to indicate that the source of the utility stream is outside the scope of the drawing.

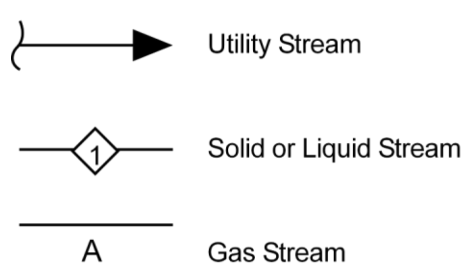

Figure 7-3. Material stream symbols

Table 7-2. Codes for Utility Streams			
Cal	- Compressed calibration gas	HS	- High pressure steam
CA	- Compressed air	IA	- Instrument air
CD	- Condensate	LS	- Low pressure steam
CW	- City (or plant) fresh water	Oil	- No. 2 or No. 6 oil
Gas	- Natural Gas		

Instruments

The presence of an instrument or a sampling port is indicated by a small circle connected to a stream line by a short dashed line, as shown in Figure 7-4. The type of instrument is indicated using the symbols listed in Table 7-3.

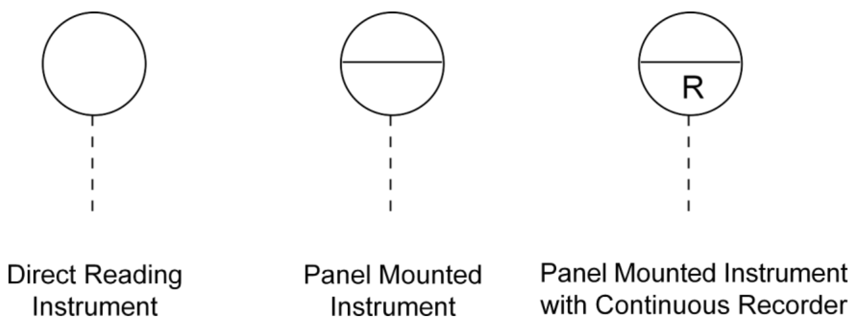

Figure 7-4. Instrument symbols

Table 7-3. Instrument Codes			
A	- Motor current	pH	- Liquid or slurry pH
CEM	- Continuous emission monitor	ΔP	- Static pressure drop
Den	- Density	SP	- Gas static pressure
F	- Flow	SSP	- Stack sampling port
L	- Liquid level	T	- Temperature
LEL	- Lower explosive limit	V	- Vacuum gauge
MP	- Measurement port	VOC	- Low concentration VOC monitor
Op	- Opacity	W	- Weight
P	Gas or liquid pressure		

Instruments such as manometers and dial-type thermometers can only be read at the gauge itself. These indicating gauges are simply denoted by the instrument circle and the instrument code. Instruments with panel-mounted gauges, usually in the control room, are indicated using a line horizontally bisecting the instrument circle. In this case, the instrument code is placed directly above the line. When the instrument indications are recorded on a continuous strip chart or with a data acquisition system, the letter "R" is placed below the line.

Materials of Construction

The materials of construction are relevant whenever there has been or may be a serious corrosion problem that could affect either system performance or safety. It is impractical to specify the exact types of material and protective coatings on each vulnerable component because there are several hundred combinations of materials and coatings in common use. However, the general type of material in certain selected portions of the system may be important. For example, it would be helpful to know that a stack discharging high concentrations of sulfuric acid vapor is composed of carbon steel because this material is easily attacked by sulfuric acid. The stack platform and access ladders could be vulnerable to failure as the corrosion problem gets progressively worse. A small set of symbols is presented in Table 7-4 for identifying materials of construction. These symbols should be placed next to the major equipment item or the gas handling ductwork segment.

Table 7-4. Codes for Construction Materials

CS	- Carbon steel	RL	- Rubber lined
FRP	- Fiberglass reinforced plastic	SS	- Stainless steel
N	- Nickel alloy	WD	- Wood

Emission Points

The stack or emission discharge point is obviously important because of visible emission observations and because of the presence of continuous emission monitors and stack sampling ports in some systems. The emission points, which should be subject to Method 9 or Method 22 visible emission observations, are identified by a set of inverted triangles immediately above the source as shown in Figure 7-5. These are numbered whenever there is any possibility of confusing different sources within a single industrial complex. The numbers used in the triangles should correspond with the emission point identification numbers used in the inspector's working files. Typical identification numbers E_1, E_2, ... E_n are used for enclosed emission points such as stacks and F_1, F_2... F_n are used for fugitive emission points such as storage piles and material handling operations.

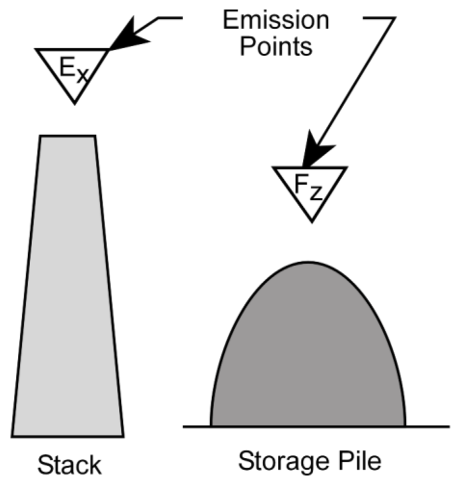

Figure 7-5. Identification of emission points

Flowchart Diagrams

Flowcharts can serve many purposes; and, as a result, many levels of sophistication in flowchart preparation exist. Some of the most complex are design-oriented piping and instrumentation drawings, termed *P&I drawings*, which show every major component, valve, and pipe within the system. Even a drawing for a relatively simple system or part of a system can have more than 500 separate items shown on it. Conversely, a simple block diagram used as a field sketch may have only 3 to 5 symbols on the drawing.

Flowcharts for air pollution control studies should be relatively simple. Generally, you need more equipment detail than shown on a simple block diagram, but far less information than provided by the standard P&I drawing. The flowcharts should not be so cluttered with system design details that it is difficult to include operating conditions that help to identify health and safety risks and performance problems. Since these are primarily working drawings, they must be small enough to be carried easily while walking around the facility. Also, the flowcharts should not require a lot of time to prepare or to revise.

Examples

An example flowchart for a relatively complicated air pollution source, a waste solvent incinerator, is shown in Figure 7-6. The process equipment in this example consists of a starved air modular incinerator with primary and secondary chambers. The air pollution control system consists of a venturi scrubber followed by a mist eliminator.

The primary and secondary chambers of the waste solvent incinerator have been shown separately because data from each chamber is important to the inspection. However, many components of the incinerator and wet scrubber systems have not been shown because their operating conditions are not central to the potential air pollution emission problems or health and safety problems.

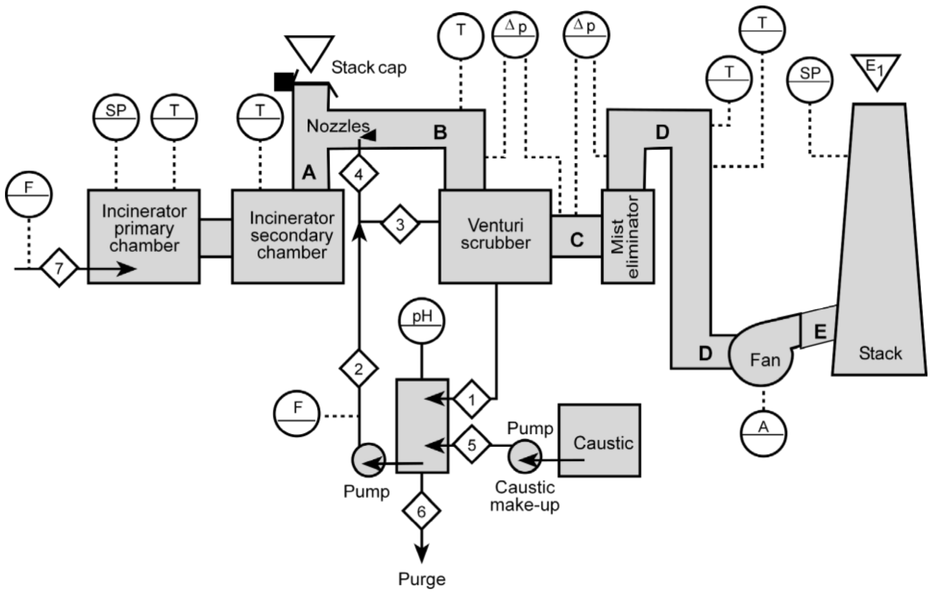

Figure 7-6. Flowchart of a waste solvent system

Another flowchart example is shown in Figure 7-7. This is a simple wet scrubber system serving a recycle operation in a hot mix asphalt plant. Most of the plant is not shown since the scrubber only controls the particulate emissions from the mixing of hot, new aggregate with cold, aged recycled asphalt pavement. The duct labeled as Section C serves as the emission discharge point. The liquid recycle pond is shown using an irregular shape and with a slightly different form of cross hatching so that it is easy to differentiate between the pond and the major equipment items.

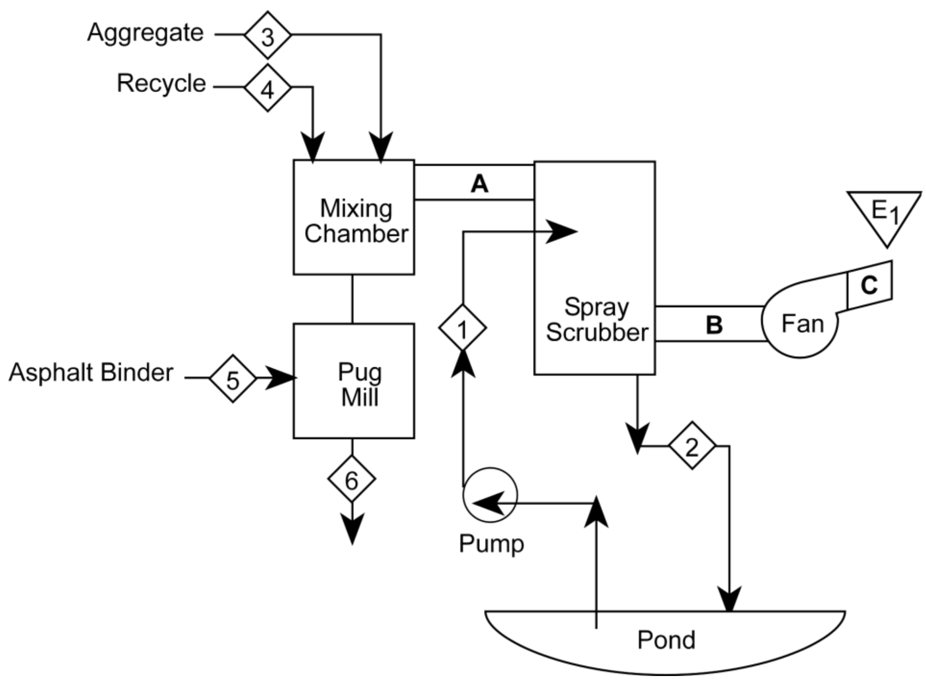

Figure 7-7. Flowchart of an asphalt plant mixing chamber

It should be noted that the symbols for the major pieces of equipment and the symbols for other parts of the system should be located in logical positions. For example, the pond in Figure 7-7 is placed near the bottom of the sketch, and the stack is in a relatively high location.

Applications

The following problems illustrate how flowcharts can be helpful during the inspection of air pollution control systems. They serve as a tool for organizing relevant data and determining what needs further investigation. Follow these steps when evaluating the overall system:

1. Determine whether the operating data are consistent and logical.
2. Compare the current data to the baseline data.
3. Determine specific areas that may need emphasis during the inspection.
4. Determine potential health and safety problems that may be encountered during the inspection.

Example Problem 1

A regulatory agency is conducting an inspection of a soil remediation unit at a hazardous waste site. This site is an abandoned chemical plant where several nonvolatile carcinogens are present in old lagoons. The plant uses a rotary kiln for destruction of the carcinogens and two side-by-side pulse jet fabric filters for control of particulate matter generated in the kiln. Based on the current data shown in Figure 7-8 and the baseline data shown in Table 7-5, determine the following:

A. Are the operating data for the system consistent and logical?
B. Do any important discrepancies exist between the current and baseline data?
C. What areas of the facility should be emphasized during the inspection?
D. What health and safety issues should be considered during the inspection?

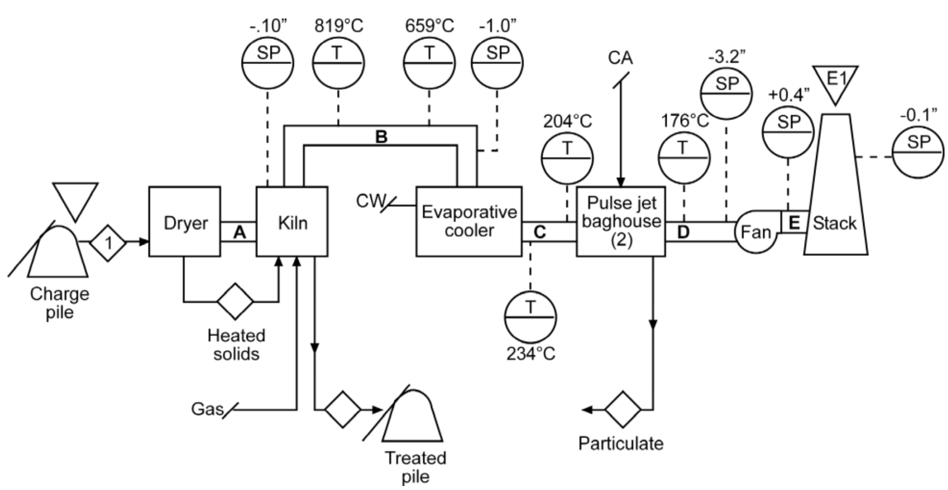

Figure 7-8. Flowchart of a hazardous waste incinerator and pulse jet baghouse system

Table 7-5. Baseline Data for the Hazardous Waste Incinerator		
Location	**Temperature (°C)**	**Static Pressure (in. H_2O)**
Kiln hood	810	-0.1
Evaporative cooler inlet	785	-1.0
Evaporative cooler outlet	240	No Data
Baghouse inlet	195	No Data
Baghouse outlet	190	-5.1
Duct E	No Data	-1.5
Stack	No Data	-1.0

Solution:

Part A

Determine if the operating data for the system are consistent and logical. There should be logical trends in the gas temperatures, gas static pressures, gas oxygen concentrations and other parameters along the direction of gas flow. For this example, the gas temperature and static pressure data are listed in Tables 7-6 and 7-7 in the direction of gas flow.

Table 7-6. Gas Temperature Profile for the Hazardous Waste Incinerator (°C)		
	Current	**Baseline**
Kiln hood	819	810
Evaporative cooler inlet	659	785
Evaporative cooler outlet	234	240
Baghouse inlet	204	195
Baghouse outlet	176	190

Table 7-7. Gas Static Pressure Profile for the Hazardous Waste Incinerator (in. H_2O)		
	Current	**Baseline**
Kiln hood	-0.10	-0.10
Evaporative cooler inlet	-1.0	-1.0
Evaporative cooler outlet	No Data	No Data
Baghouse inlet	No Data	No Data
Baghouse outlet	-3.2	-5.1
Duct E	+0.4	-1.5
Stack	-0.1	-1.0

The gas temperature and static pressure trends through the system are both logical. The gas temperatures are at a maximum at the discharge of the kiln and decrease throughout the system. The gas temperature at the fan outlet is not provided for this example. Note that sometimes gas temperature at the fan outlet is *higher* than that at the fan inlet due to compression that occurs as the gas moves through the fan. The static pressures become progressively more negative as the gas approaches the fan. After the fan, the static pressure of the system significantly increases, as expected. Since the set of plant instruments provides consistent and logical profiles through the system, they are probably relatively accurate.

Part B

Compare the current data to the baseline data to determine if any important discrepancies exist.

Step 1. Use Table 7-6 to compare the current temperature data to the baseline data.

a. Evaluate the destruction efficiency of the rotary kiln using the kiln outlet temperature data.

   The primary function of this portable plant is to incinerate the contaminated soil. It is apparent from the flowchart that the most useful single parameter for evaluating the destruction efficiency of the rotary kiln system is the kiln outlet temperature monitored by the temperature gauge on the left side of duct B. The present value of 819°C compares well with the baseline data obtained during the trial burn tests in which the unit demonstrated good performance. Accordingly, it appears that the unit is presently in compliance.

b. Evaluate the temperature data for Duct B.

   The 160°C temperature drop (from 819°C to 659°C) in the short duct between the kiln and the evaporative cooler is relatively new. The baseline data indicate that the previous temperature drop was 25°C. The significantly higher temperature drop currently occurring across this section indicates that significant air infiltration is probably happening. This air infiltration could reduce the amount of combustion gas being pulled from the kiln, resulting in fugitive emissions. A check for fugitive emissions should be included in the scope of the inspection.

c. Evaluate the temperature data for the evaporative cooler.

   The evaporative cooler is important because it protects the Nomex® bags used in the downstream pulse jet baghouses from excessive temperatures. It is clear from the flowchart that currently there is a gas temperature drop of 425°C across the evaporative cooler. This fact combined with an observed outlet gas temperature of 234°C demonstrates that this unit is operating as intended. It is not necessary to climb to the top of the unit to check the spray nozzles.

d. Evaluate the temperature data for the baghouse.

The data indicate a severe temperature drop across the baghouse (28°C). This is most likely due to air infiltration, and this should be evaluated during the field inspection.

Step 2. Use Table 7-7 to compare the current pressure drop data to the baseline data.

a . Evaluate the static pressure data at the kiln.

The baseline data and the current data are in agreement.

b. Evaluate the static pressure drop from the evaporative cooler inlet to the baghouse outlet.

The baseline static pressure drop is 4.1 in. H_2O and the current pressure drop is 2.2 in. H_2O. Pressure drops across evaporative coolers tend to remain constant. However, the pressure drop across baghouses can vary due to changes in dust concentration or because of a malfunction. A decrease in pressure drop may result in a pulse jet baghouse if there is air infiltration in the area between the upper tube sheet and the collector outlet. Since the temperature data indicate a possible air infiltration problem, this area should be checked visually during the field inspection.

c. Evaluate the static pressure data from the baghouse exit to the stack.

The static pressure increase created by the fan (3.6 in. H_2O) is similar for the baseline and current conditions. The static pressure drop from the fan exit to the stack is also in agreement.

Part C

The areas that should be emphasized during the filed inspection as follows:

- Check for air infiltration in Duct B.
- Check for fugitive emissions from the rotary kiln.
- Investigate reasons for the temperature drop across the pulse jet baghouse.
- Check for air infiltration across the pulse jet baghouse.

Part D

Determine what health and safety issues should be considered during the performance evaluation.

The pulse jet baghouse should be one of the main areas evaluated during the field portion of the inspection. However, this work must be conducted carefully in order to minimize safety hazards. The roof of the unit should be avoided because it is an uninsulated metal surface at 176°C (349°F). The soles of safety shoes could begin to melt and cause a fall.

Furthermore, there is a slight possibility of falling through the roof of the baghouse. The gas temperature drop of 28°C across the baghouse indicates severe air infiltration that may be caused by corrosion. If so, the roof may have been weakened. Corrosion is very likely in this process due to the formation of hydrochloric acid and water vapor in the kiln.

The waste being burned in this portable plant includes several suspected carcinogens. This should be noted on the flowchart to serve as a reminder to stay out of areas where inhalation problems or skin absorption hazards could exist.

Example Problem 2

A company is routinely evaluating the performance of a venturi scrubber serving a hazardous waste incinerator. They are using an Enhanced Monitoring Protocol that is based on the static pressure drop gauge across the venturi. Answer the following questions based on the data shown in Figure 7-9.

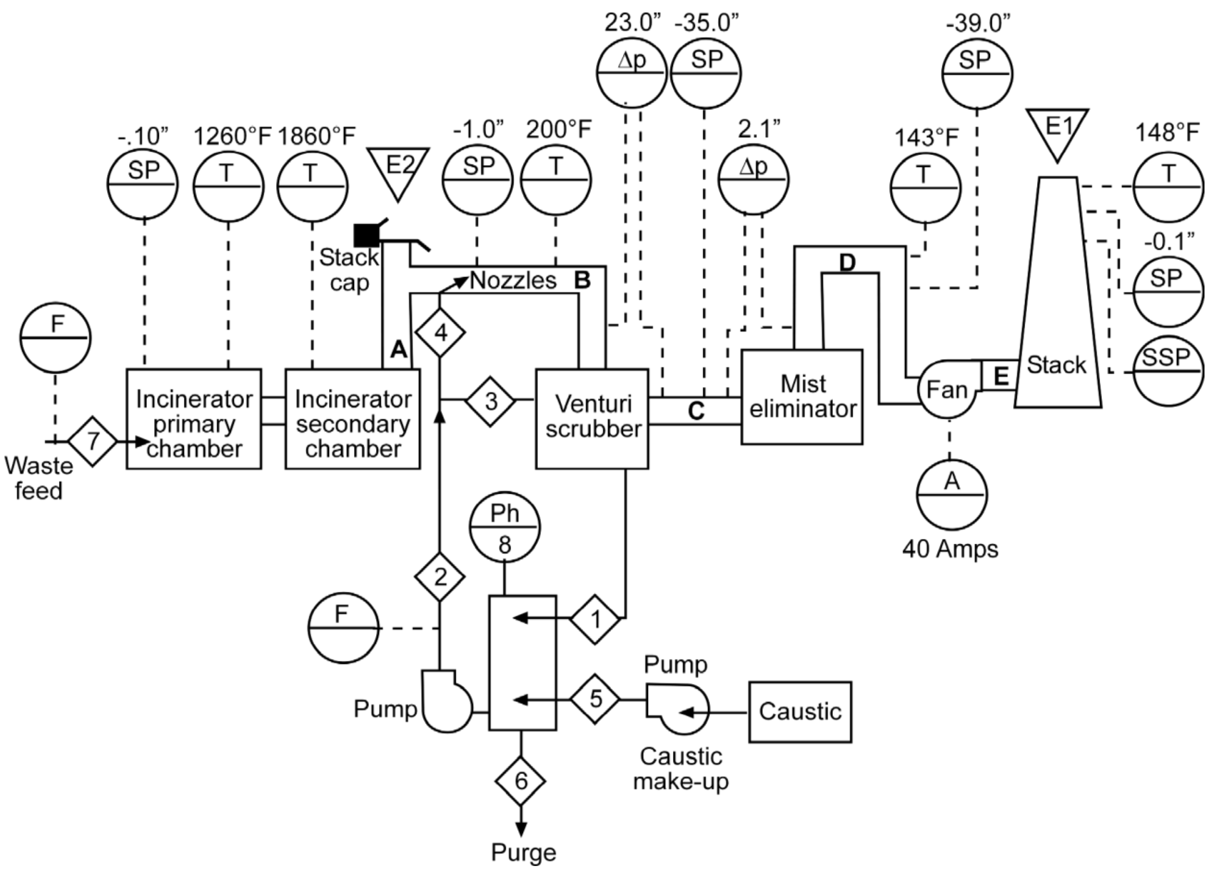

Figure 7-9. Flowchart of a hazardous waste incinerator and venturi scrubber system

A. Is there any reason to believe that the venturi scrubber pressure drop gauge is malfunctioning?
B. Is there any reason to be concerned about fugitive emissions from the emergency bypass stack?

The current data and the corresponding baseline data are provided in Tables 7-8 and 7-9.

Table 7-8. Static Pressures and Static Pressure Drops (in. H_2O)		
	Current	**Baseline**
Static Pressures		
Incinerator primary chamber	-0.10	-0.12
Duct B	-1.0	-1.10
Mist eliminator inlet	-35.0	-38.0
Fan Inlet (Duct D)	-39.0	-40.0
Stack	-0.1	-0.1
Static Pressure Drop		
Venturi scrubber	23.0	36.0
Mist eliminator	2.1	1.6

Table 7-9. Gas Temperatures (EF)		
	Current	**Baseline**
Incinerator secondary chamber	1860	1835
Duct B	200	197
Fan Inlet	143	142
Stack	148	147

Solution:

Part A

First, evaluate the quality of data before attempting to evaluate the system. There should be logical trends for the static pressures, gas temperatures, and other relevant parameters.

The static pressure and pressure drop data have been combined into a single graph (Figure 7-10), which can be used to evaluate the static pressures along the entire gas flow path. It is apparent that the current static pressure drop for the venturi scrubber does not make sense. The current mist eliminator inlet static pressure and fan inlet static pressure data suggest that the static pressure drop across the venturi scrubber should be higher than indicated by the gauge. It is quite possible that the venturi scrubber pressure drop gauge is malfunctioning and that the actual static pressure drop is relatively similar to the baseline value of 36 in. H_2O.

Part B

There is no reason to suspect fugitive emissions from the emergency bypass stack. The static pressures upstream and downstream of the bypass stack are negative. Accordingly, ambient air could leak into the stack if it were poorly sealed; however, untreated gases could not escape.

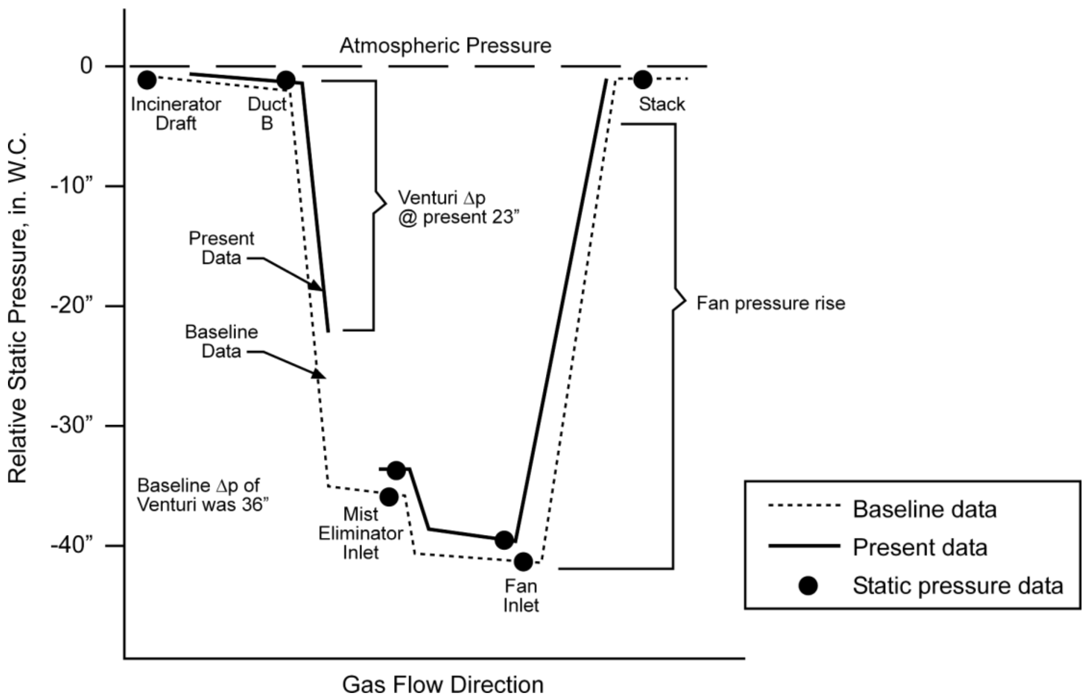

Figure 7-10. Static pressure profiles

Review Problems

Use the figure shown below to answer Questions 1-3.

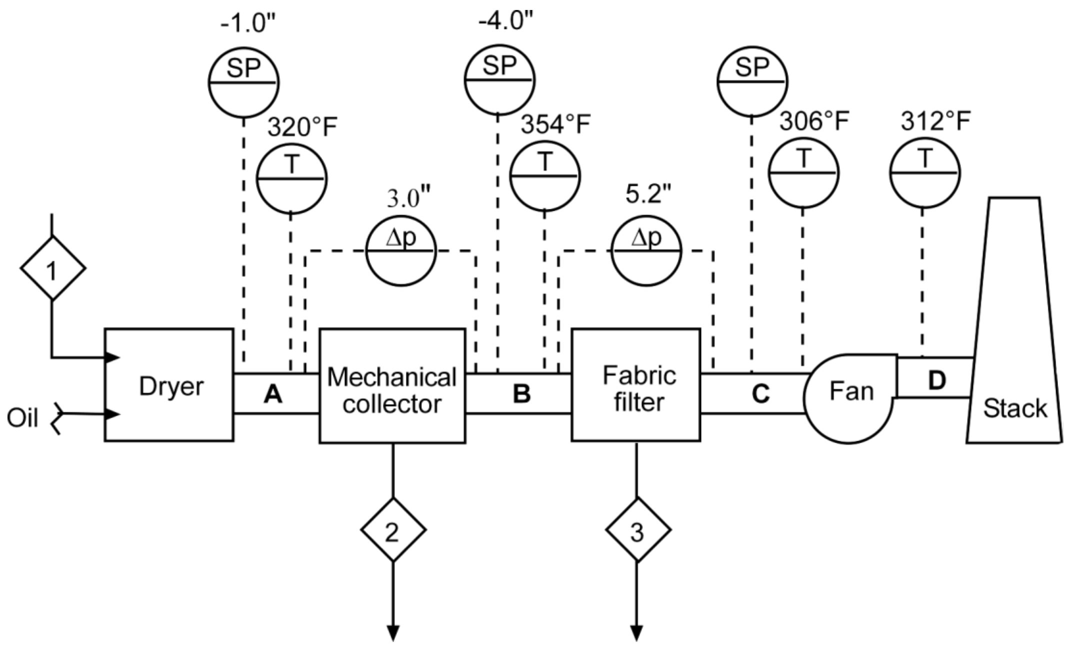

Figure 7-11. Example flowchart

1. Which static pressure reading appears to be illogical according to the flowchart?

    a. Duct A
    b. Duct B
    c. Duct D
    d. They all appear logical.

2. Estimate the static pressure at the inlet to the fan.

    a. +0.7 in. H_2O
    b. -1.7 in. H_2O
    c. -9.2 in. H_2O
    d. None of the above

3. The temperature in Duct A was checked by plant personnel and determined to be correct. Which of the other temperature readings appears to be illogical according to the flowchart?

    a. Duct B
    b. Duct C
    c. Duct D
    d. They all appear logical.

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